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13. ABSTRACT *(Maximum 200 words)*

This program investigated the role of processing on the high temperature creep behavior of polycrystalline alumina reinforced with SiC whiskers or particulates. Three types of tests were conducted. First, creep data were obtained on monolithic unreinforced alumina and on alumina composites reinforced with SiC whiskers or SiC particulates. Second, the effect of processing was investigated by testing conventionally processed composites and composites produced using a dispersion processing procedure. Third, the role of anelasticity was investigated by conducting stress removal experiments. A full description of the results of this program are contained in the publications documented in this report.

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EFFECT OF PROCESSING PARAMETERS ON THE HIGH TEMPERATURE CREEP OF SiC WHISKER-REINFORCED ALUMINA

Final Progress Report

Terence G. Langdon

September 27, 1996

U.S. ARMY RESEARCH OFFICE

Grant Number DAAL03-91-G-0230

University of Southern California

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Statement of the problem:

The inherent brittleness exhibited by most monolithic ceramic materials impedes their potential applications as structural components. One established method of enhancing the toughness of ceramics is to add reinforcements to form composites. It is now known that alumina matrix composites reinforced with silicon carbide whiskers exhibit improved toughness at room temperature and better creep resistance at elevated temperatures.

This research program was initiated in order to investigate the role of processing on the creep properties of whisker-reinforced alumina at elevated temperatures. The program was prompted by the possibility of changing the morphology of the whisker additions using a procedure known as dispersion processing. In addition, experiments were undertaken to compare the effect on high temperature creep of using SiC whiskers and SiC particulates. Finally, the program was also used to investigate the role of anelastic creep recovery in these composite materials.

Summary of major results:

The results obtained in this program have been fully reported in the scientific literature and a complete listing of the relevant publications is included in this report. The major findings may be summarized briefly as under:

1. Creep tests were conducted on an alumina composite reinforced with ~9 vol % SiC whiskers. The creep curves exhibited a well-defined steady-state region with failure strains up to >10% and a stress exponent of ~3.8. The results demonstrate that the presence of whiskers in the grain boundaries inhibits the occurrence of Lifshitz grain boundary sliding so that diffusion creep is suppressed. The composite deforms instead by an intragranular dislocation process controlled by lattice diffusion of the oxygen anions.

2. If the whisker volume fraction is increased to ~18 and ~30 vol %, there is a tendency to form agglomerates in conventionally processed composites and this leads to an increase in both the stress exponent and the activation energy for creep. The high value of ~6.3 for the stress exponent in the composite containing 30 vol % SiC whiskers may be lowered to ~3 by incorporating a threshold stress into the analysis. This threshold stress is associated with the interaction between mobile dislocations and the SiC whiskers.

3. The fracture behavior of the composites changes with the volume fraction of SiC whiskers because of the tendency to form whisker agglomerates. Whisker pull-outs are visible after creep testing at elevated temperatures with high volume fractions of SiC whiskers because the interfaces are weaker and there is a preferential debonding due to the formation of cracks at the whisker-matrix interfaces. Crack networks occur at the higher volume fractions of whiskers because cracks propagate preferentially along the whisker-free channels.

4. Dispersion processing was used to obtain a relatively homogeneous distribution of SiC whiskers without any tendency to form whisker agglomerates. Creep testing demonstrated that this processing procedure was superior to conventional hot pressing because there was very considerable creep strengthening. For example, conventional processing typically reduces the creep rate by approximately one order of magnitude by comparison with unreinforced monolithic alumina, whereas the results obtained in this program show that dispersion processing is capable of reducing the creep rate by up to three orders of magnitude.

5. The aspect ratio of the SiC whiskers is an important parameter governing the creep strength. Detailed creep testing showed that the creep rates are reduced when the aspect ratio is reasonably high (~30). These results were interpreted in terms of the formation of a network of interconnected whiskers which are capable of supporting some of the load.

6. To check the possible occurrence of a whisker network, the anelastic properties were measured in monolithic alumina and in alumina composites reinforced with either SiC whiskers or SiC particulates. No anelastic response was visible on load removal during testing of the monolithic material or a composite containing 5 vol % of particulates. However, there was a significant anelastic response in composites reinforced with 15 vol % of either whiskers or particulates. These results support the proposal that there is an interconnecting network within the material, especially when it is noted that 15 vol % of particulates is very close to the percolation threshold of ~16 vol % which leads to >90% of the particles forming a continuous network through the material.

Publications from this award:

1. K. Xia, J.R. Porter and T.G. Langdon, "The Influence of Processing on the High Temperature Mechanical Properties of a Whisker-Reinforced Alumina Composite," Processing, Fabrication, and Manufacturing of Composite Materials (T.S. Srivatsan and E.J. Lavernia, eds.), pp. 253-264. ASME, New York, NY (1992).

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3. W. Gu, J.R. Porter and T.G. Langdon, "Evidence for Anelastic Creep Recovery in Silicon Carbide-Whisker-Reinforced Alumina," Journal of the American Ceramic Society 77, 1679-1681 (1994).

4. K. Xia and T.G. Langdon, "Analysis of Deformation Mechanisms in the High Temperature Creep of an Alumina Matrix Composite Reinforced with Silicon Carbide Whiskers," Strength of Materials: Proceedings of the 10th International Conference on the Strength of Materials (H. Oikawa, K. Maruyama, S. Takeuchi and M. Yamaguchi, eds.), pp. 765-768. The Japan Institute of Metals, Sendai, Japan (1994).

5. K. Xia and T.G. Langdon, "The Toughening and Strengthening of Ceramic Materials through Discontinuous Reinforcement," Journal of Materials Science 29, 5219-5231 (1994).

6. K. Xia and T.G. Langdon, "High Temperature Deformation of an Alumina Composite Reinforced with Silicon Carbide Whiskers," Acta Metallurgica et Materialia 43, 1421-1427 (1995).

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11. W. Gu, J.R. Porter and T.G. Langdon, "An Investigation of Anelastic Creep Recovery in SiC Whisker and Particulate Reinforced Alumina," Ceramic Engineering and Science Proceedings 16, 247-251 (1995).

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13. K. Xia, W. Gu and T.G. Langdon, "Influence of Processing Parameters on the Creep Behavior of Whisker-Reinforced Alumina Composites," Silicates Industriels 61, 33-38 (1996).

14. K. Xia and T.G. Langdon, "Fracture Behavior at Elevated Temperatures of Alumina Matrix Composites Reinforced with Silicon Carbide Whiskers," Journal of Materials Science 31, 5487-5492 (1996).

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